Relative Radiation Risk Reduction for Small Spacecraft and New Designers

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NASA GSFC Code 561

Flight Data Systems & Radiation Effects Branch

To be presented by Michael Campola at the Electrical, Electronic, and Electromechanical (EEE) Parts for Small Missions, Greenbelt, MD, September 10-11, 2014.
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>COTS</td>
<td>Commercial Off The Shelf</td>
</tr>
<tr>
<td>DDD</td>
<td>Displacement Damage Dose</td>
</tr>
<tr>
<td>DOA</td>
<td>Dead On Arrival</td>
</tr>
<tr>
<td>EEE</td>
<td>Electrical, Electronic, and Electromechanical</td>
</tr>
<tr>
<td>ELDRS</td>
<td>Enhanced Low Dose Rate Sensitivity</td>
</tr>
<tr>
<td>NEPP</td>
<td>NASA Electronic Parts and Packaging</td>
</tr>
<tr>
<td>RHA</td>
<td>Radiation Hardness Assurance</td>
</tr>
<tr>
<td>SEE</td>
<td>Single Event Effect</td>
</tr>
<tr>
<td>SWaP</td>
<td>Size Weight and Power</td>
</tr>
<tr>
<td>TID</td>
<td>Total Ionizing Dose</td>
</tr>
</tbody>
</table>
Definitions

• Small Spacecraft
  o Mass < 180kg (Small Spacecraft Technology Program)
  o Can be any class mission!
  o Independent of cost, not solely small budgets

• Relative Risk
  o Ratio of the probability of an event occurring in an exposed group to the probability of the event occurring in a comparison, non-exposed group (Wikipedia)
  o Relative risk includes two important features:
    » Comparison of risk between two "exposures" puts risks in context
    » "Exposure" is ensured by having proper denominators for each group
  o Not absolute risk

• New Designers – Anyone: EEE Technology or Implementation
Introduction

• Aim and Focus
  o Design trade impacts on radiation
  o Dealing with relative risk
    » Accounting for all known risks to the system
    » Categorizing risk based on manifestation at the system level
    » Ranking priorities based on failure threats
  o Use in class practices
    » Risk identification and comparison
    » Test methodologies should be tied to physics of failure

• What I am Not Covering
  o RHA is RHA, not redefining
  o Board-level testing
  o Reducing test requirements
  o Substitute radiation tests
    » Proton testing for combined TID and SEE
    » Laser vs. heavy ion testing

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Small Spacecraft “Market Research”

- CubeSat/SmallSat Subsystem Vendors (cubesat.org)
  - Not going to help radiation concerns when trying to drive costs down, do not know your mission objectives
  - Using COTS components in many sub-systems

- Small Spacecraft With New Designers
  - Universities
  - Government Institutions
  - Collaborations

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New Designer Scale and Success

University-Class Spacecraft (through 2013)

Success Rates, First Launches (2000-2014)

Data from Professor Michael Swartwout at St. Louis University:
https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database

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Rational Approach

1. Smart Requirements
2. Evaluate Design/Components
   • Visualize Design Impacts
3. Smart Engineering Decisions with Designers
   • Risk Buy Down
   • Categorize and Rank Risks
4. Iterate Process

(After K. A. LaBel, NEPP 2010)
1. Smart Requirements

- **Reliability Requirements**
  - System Requirements
  - Subsystem functionality
  - Flow down to modules / parts

- **Design Hardening**
  - Technology Selection
    - Part Selection
    - Fault Tolerance
    - Operating conditions

- **Performance Requirements**
  - Vulnerability
    - Function
    - Reliability

**System → Sub-system → Parts**

(After Gigliuto, 2013)

- **Free-Field Environment Definition**
  - Mission
  - Trajectory and timing

- **Shielding**
  - Specific to Box
    - Thickness vs. Materials

- **Internal Environment Definition**
  - Specific to Device
    - Spot Shielding

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2. Evaluate Design/Components

• Visualizing Design Impacts
  o Mission Duration & Redundancy
    » Environmental Hazard: Benign or Harsh (considered for SEE or TID/DDD)
    » System Level Impact: Manageable or Mission Loss?
    » Early Degradation (ELDRS, TID lot variations, etc.)

• The “we can’t test everything” approach
  o “Please Excuse My Dear Aunt Sally”
    » $4 + 2 \times 3 = (4 + 2) \times 3 = 6 \times 3 = 18$
    » $4 + 2 \times 3 = 4 + (2 \times 3) = 4 + 6 = 10$
  o Requirements and risk impacts should determine the order of operations = Relative Radiation Risks
Short Mission → Long Mission

Environmental Hazard

Mission Loss

RISK

Manageable

Benign

Harsh

Early Degradation
Degradaion

Destructive or Critical SEE

Mitigated SEE

Non-Critical SEE

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Single String → Redundancy

Mission Loss

RISK

Manageable

Benign

Harsh

Environmental Hazard

Early Degradation

Degradation

Destructive or Critical SEE

Mitigated SEE

Non-Critical SEE

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3. Smart Engineering Decisions

- Be conscious of design trades
  - SWaP trades need to be carefully considered
  - Parts replacement/mitigation schemes
- Test where it solves problems and reduces system risk (risk buy down)
- Categorize and rank the risks relative to one another
Risk Buy Down by Radiation Testing

<table>
<thead>
<tr>
<th>Required Mission Success per Spacecraft Flown</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
</tr>
</tbody>
</table>
| High  
| Medium |
| Low   |
| TID/DDD SEE |

| 50%  |
| High  
| Medium |
| Low   |
| TID/DDD SEE |

| 10%  |
| High  
| Medium |
| Low   |
| TID/DDD SEE |

<table>
<thead>
<tr>
<th>Required LEO Mission Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Months</td>
</tr>
<tr>
<td>High</td>
</tr>
<tr>
<td>Medium</td>
</tr>
<tr>
<td>Low</td>
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Categorize and Rank Risks

- Translation of a 5x5 to Relative Risk
  - Consequence \times Relative Risk
  - Relative risk is ratio of worst consequence probability to lowest risk probability (0 to 1)
  - Similar to tracking top risks

- 4. Iterate the process

<table>
<thead>
<tr>
<th>CONSEQUENCES</th>
<th>LIKELIHOOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Ongoing Effort

• Design trades drive the risks
  o Know these trades and their effect on radiation concerns
  o Some simple questions can determine major radiation concerns and how to deal with them:
    » Mission Life
    » Orbit
    » Redundancy
    » Device Process, Family, Function
    » Class
  o Internal effort to raise awareness

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Questions?

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